Chapter 7
Dissolved Oxygen Monitoring in the Stockton Ship Channel

Introduction

Dissolved oxygen levels in the Stockton Ship Channel have been monitored by staff of the Bay-Delta Monitoring and Analysis Section during the late summer and fall of each year since 1968. Due to a variety of factors, dissolved oxygen levels have historically fallen in the central and eastern portions of the channel during this period. Some of the factors responsible include low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow in the San Joaquin River past Stockton.

Because low dissolved oxygen levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, California has established specific water quality objectives to protect these uses. Within the channel, two separate dissolved oxygen objectives have been established. The Central Valley Regional Water Quality Control Board has adopted a dissolved oxygen standard of 5.0 mg/L for the entire Delta throughout the year to protect all beneficial uses (CVRWQCB 1998). The State Water Resources Control Board (SWRCB) has an objective of 6.0 mg/L in the lower San Joaquin River between Stockton and Turner Cut (which includes the eastern portion of the Stockton Ship Channel). The SWRCB's objective applies from September through November to provide greater protection to migrating fall-run Chinook salmon (SWRCB 1995).

As part of a 1969 Memorandum of Understanding between the Department of Water Resources (DWR), the US Fish and Wildlife Service, the US Bureau of Reclamation, and the Department of Fish and Game (DFG), DWR has installed a rock barrier across the head of Old River during periods of projected low fall San Joaquin River outflow. This Head of Old River Barrier (Barrier) increases net flows down the San Joaquin River past Stockton. The higher flows can contribute to improving dissolved oxygen concentrations within the channel. Because of bank erosion and barrier overtopping concerns, the Barrier is usually installed when average daily San Joaquin River flows past Vernalis are projected to be approximately 2,000 cfs or less.

DWR completed installation of the Barrier on September 15, 2003, (the closure was fully operational by September 22) because late summer San Joaquin River flows past Vernalis were low (average September daily San Joaquin River flow past Vernalis was 1,383 cfs), and early fall flows were not projected to be sufficient to alleviate dissolved oxygen concerns in the eastern channel. Removal of the Barrier occurred between November 3 and November 13, 2003.

Methods

Figure 7-1 Monitoring sites in the Stockton Ship Channel

Dissolved oxygen concentrations in the Stockton Ship Channel were monitored by vessel on eight monitoring runs from August 11 to December 10, 2003[1]. During each of the monitoring runs, fourteen sites were sampled at low water slack, beginning at Prisoners Point (Station 1) in the central Delta and ending at the Stockton Turning Basin at the terminus of the ship channel (Station 14). An exception to this standard protocol occurred during the November 14 sampling run, when stations 1 through 9 were sampled at high water slack due to a miscalculation of the vessel departure schedule. For geographic reference and to simplify reporting, the sampling stations are keyed to channel light markers[2] as shown in Figure 7-1.

Because monitoring results differ along the channel[3], sampling stations are grouped into western, central, and eastern regions within the channel; these regions are highlighted in Figure 1. The western channel begins at Prisoners Point (Station 1) and ends at Light 14 (Station 5). The central channel begins at Light 18 (Station 6) and ends at Light 34 (Station 9). Finally, the eastern channel begins at Light 40 (Station 10) and ends at Light 48 (Station 13). The Turning Basin (Station 14) is unique within the channel because it is east of the entry point of the San Joaquin River into the channel and isolated from down-channel flow. Because of the unique hydromorphology of Station 14, the findings for this station are discussed separately from those of the other channel stations.

Discrete samples were taken from the top (1 meter from surface) and bottom (1 meter from bottom) of the water column at each station at low water slack, and analyzed for dissolved oxygen concentrations and temperature. Top dissolved oxygen samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method (APHA 1998). Bottom dissolved oxygen samples were obtained using a Seabird submersible sampler and measured using aYSI polarographic electrode (Model No. 5739) with a Seabird CTD 911+ data logger. Surface and bottom water temperatures were measured using a YSI 6600 sonde equipped with a Model No. 6560 thermistor temperature probe, or a Seabird SBE3 temperature probe.

Flow data for the San Joaquin River at Vernalis were obtained from station data at Vernalis compiled by DWR[4]. Average daily flows past Vernalis were obtained by averaging 15-minute data for a daily average flow rate. Tidal cycles of ebb and flood are not seen in flows at Vernalis and flow is downstream (positive) throughout the year. The San Joaquin River flows past Stockton used in this report were obtained from data recorded by the

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[1] Funding for these special studies was provided by the Division of Operations and Maintenance, DWR

[2] Channel light markers are ship navigational aides placed in navigable waters. Although they are not spaced at fixed intervals, they provide convenient landmarks for identifying sample locations.

[3] The findings of previous fall studies have shown that fall dissolved oxygen levels are typically: robust and high (7.0-9.0 mg/L) in the western Channel; transitional, variable (4.0-7.0 mg/L), and stratified in the central Channel; and low (3.0-5.0 mg/L) and stratified in the eastern Channel.

[4] Station information: DWR Station SJR at Vernalis, RSAN112

US Geological Survey (USGS) flow monitoring station southeast of Rough and Ready Island [5].

Flow rates in the San Joaquin River at Stockton are heavily influenced by tidal action, with daily ebb and flood tidal flows of 3,000 cfs or greater in either direction. To calculate net daily flows, the tidal pulse is removed from the USGS 15-minute flow data with a Butterworth filter[6] to yield net daily flow. Because of low flows at Vernalis, local agricultural diversions, and export pumping, net daily flows at Stockton can sometimes reverse direction. Although net flows at Stockton frequently approached zero during this study period, net daily reverse flows were seen only during the end of fall 2003.

In this report, we define a dissolved oxygen "sag" as a region within the channel where dissolved oxygen levels are < 5.0 mg/L. A dissolved oxygen "depression" is defined as a region within the channel where dissolved oxygen levels are ≥ 5.0 mg/L but < 6.0 mg/L.

Results

During this study period (August 11 to December 10), dissolved oxygen levels varied considerably between regions within the channel from a low of 3.0 mg/L to a high of 10.7 mg/L. In the western channel dissolved oxygen concentrations were relatively high and stable, ranging from 6.9 to 9.4 mg/L. The robustness of dissolved oxygen concentrations in this portion of the channel is apparently due to greater tidal mixing, the absence of conditions creating BOD, and shorter hydrological residence time. In the central portion of the channel, dissolved oxygen concentrations were more variable than the concentrations observed in the western channel, ranging from 4.1 to 9.3 mg/L. In the eastern channel, the dissolved oxygen levels were the most variable and stratified, ranging from a low of 3.0 mg/L to a high of 10.7 mg/L. Changing inflows from the San Joaquin River into the eastern channel may partially account for the variability of the dissolved oxygen levels within the eastern channel.

The findings for the late summer and fall of 2003 are briefly summarized by month as follows.

August

Monitoring on August 11 showed surface dissolved oxygen levels ranging from 4.7 mg/L at stations 9 and 10 in the central and east channels, respectively to 8.5 mg/L at Station 1 in the west channel (Figure 7-2). Bottom dissolved oxygen levels ranged from 3.8 mg/L at Station 12 in the east channel to 8.9 mg/L at Station 2 in the west channel. Both a dissolved oxygen sag and a depression were observed at the surface and bottom in the central and eastern channels. The depression extended from stations 8 to 13, while the sag occurred from stations 9 to 12 in the eastern channel. The western channel exhibited the highest dissolved oxygen and all stations maintained dissolved oxygen levels above 7.5 mg/L.

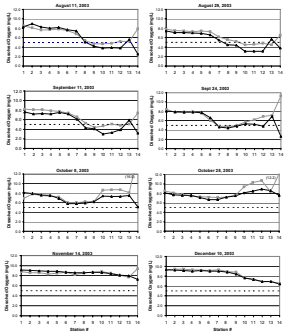

Figure 7-2 Surface and bottom dissolved oxygen concentrations in the Stockton Ship Channel, Fall 2003

[5] Station information: USGS 304810 SJR at Stockton, RSAN063.

[6] The USGS uses a Butterworth bandpass filter to remove frequencies (tidal cycles) from 15 minute flow data, that occur on less than a 30-hour period. The resulting 15-minute time-series is then averaged to provide a single daily value that represents net river flow exclusive of tidal cycles.

On August 11, water temperature values ranged from surface values of 21.8 °C in the west channel to 26.1 °C in the east channel, and bottom values ranged from 21.6 °C in the east to 25.3 °C in the west channel (Figure 7-3).

Monitoring on August 29 showed surface dissolved oxygen levels ranging from 4.5 mg/L in the east channel to 7.8 mg/L in the west. Bottom dissolved oxygen levels ranged from 3.1 mg/L in the east channel to 7.4 mg/L in the west. A dissolved oxygen sag occurred at both the surface and bottom of the water column from stations 10 to 12 in the eastern channel. The western channel exhibited the highest dissolved oxygen concentrations and all stations maintained surface dissolved oxygen levels above 7.3 mg/L.

August 29 water temperature values ranged from surface values of 22.6 °C in the west channel to 26.2 °C in the east. Bottom values ranged from 22.5 °C in the west to 25.4 °C in the east channel (Figure 7-3).

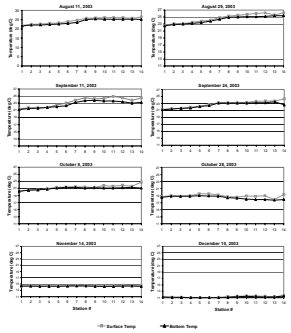

Figure 7-3 Surface and bottom water temperatures in the Stockton Ship Channel, Fall 2003

Average daily flows in the San Joaquin River past Vernalis in August ranged from 1,265 to 1,655 cfs. Net flow in the San Joaquin River past Stockton ranged from 124 to 626 cfs from August 1 through 26, the period of time the flow meter was in operation (Figure 7-4).

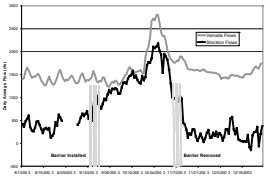

Figure 7-4 Fall 2003 San Joaquin River Flow at Stockton and Vernalis

September

On September 11, surface dissolved oxygen levels ranged from 4.4 mg/L at Station 9 in the central channel to 8.2 mg/L at Station 1 in the west channel. Bottom dissolved oxygen levels ranged from 3.0 mg/L at station 10 in the east channel to 7.6 mg/L at Station 1 in the west channel. A dissolved oxygen sag occurred at both the surface and bottom, extending from stations 8 to 13 in the eastern channel. The western channel exhibited the highest dissolved oxygen and all stations there maintained surface dissolved oxygen levels above 7.2 mg/L (Figure 7-2).

On September 11, surface water temperatures ranged from 21.4 °C at Station 1 in the west channel to 24.9 °C at Station 11 in the east channel. Bottom temperatures ranged from 21.2 °C at Station 1 to 23.8 °C at Station 9 in the central channel (Figure 7-3).

On September 24, surface dissolved oxygen levels ranged from 4.7 mg/L at Station 8 in the central channel to 8.4 mg/L at Station 1. Bottom dissolved oxygen levels ranged from 4.4 mg/L at Station 8 in the central channel to 8.0 mg/L at Station 1. Dissolved oxygen sags occurred at the surface in the central channel at stations 7 and 8; at the bottom in the central channel from stations 7 to 9; and in the eastern channel at Station 12. The western channel exhibited the highest dissolved oxygen and all stations there maintained surface dissolved oxygen levels above 7.6 mg/L (Figure 7-2).

Surface water temperature ranged from 21.3 °C at Station 1 to 23.7 °C at stations 12 and 13 in the eastern channel on September 24. Bottom temperatures ranged from 21.2 °C at Station 1 to 23.5 °C at Station 13 (Figure 7-3).

September flows in the San Joaquin River at Vernalis were similar to those in August and remained fairly steady, ranging from 1,233 to 1,535 cfs. DWR

began installation of the barrier at the head of Old River on September 2. The closure was completed on September 15 and all culverts were closed on September 22. Coincident with the Barrier placement, net flow past Stockton increased steadily during the month, which resulted in an increase in flow rates from 406 cfs in early September to 1,206 cfs at the end of the month[7] (Figure 7-4).

October

On October 8, surface dissolved oxygen levels ranged from 6.0 mg/L at stations 6 and 7 in the central channel to 8.7 mg/L at stations 11 and 12 in the east channel. Bottom dissolved oxygen levels ranged from 5.9 mg/L in the central channel at stations 6, 7 and 8 to 8.1 mg/L at Station 1. A dissolved oxygen sag was not observed within the channel; however, a very slight dissolved oxygen depression occurred on the bottom at stations 6, 7 and 8 in the central channel.

On October 8, surface water temperatures ranged from 20.3 °C at Station 1 in the west channel to 21.9 °C at Station 12 in the east channel. Bottom temperatures ranged from 20.2 °C at Station 1 to 21.3 °C at stations 6, 7, and 13.

Surface dissolved oxygen levels on October 28 ranged from 7.1 mg/L at Station 7 in the central channel to 10.7 mg/L at Station 12 in the east channel. Bottom dissolved oxygen levels ranged from 6.7 mg/L at stations 6 and 7 to 8.9 mg/L at Station 12. A dissolved oxygen sag was not observed within the channel during this sampling run. The eastern channel exhibited the highest dissolved oxygen and all stations maintained surface dissolved oxygen levels above 7.1 mg/L.

On October 28 surface water temperatures ranged from 17.9 °C in the east channel at Station 13 to 19.5 °C in the west channel at stations 4 and 5. Bottom temperatures ranged from 17.7 °C at Station 13 to 19.0 °C at Station 5.

Average daily flows of the San Joaquin River at Stockton ranged from 1,085 to 2,182 cfs, increasing steadily throughout the month (Figure 7-4). Flows recorded at Stockton were very similar to those measured at Vernalis for much of the month, indicating that little upstream diversion was occurring. The Barrier at Old River was in place with all culverts closed for the entire month of October. Flow rates at Vernalis ranged from 1,283 to 2,804 cfs and also increased steadily throughout the month.

November

Dissolved oxygen readings throughout the channel remained well above state objectives in November, and the Barrier was removed in early November. On November 14 surface dissolved oxygen levels ranged from 7.7 mg/L at Station 13 to 8.8 mg/L at stations 1 and 10. Bottom dissolved oxygen levels ranged from 8.0 mg/L at Station 13 to 9.1 mg/L at stations 1 and 2 (Figure 7-

[7] USGS flow data for the San Joaquin River at Stockton was not available for the first four days in September (9/1 – 9/4).

2). Although dissolved oxygen readings were fairly consistent throughout the channel, dissolved oxygen levels in the east were slightly lower than those seen in the central and western channels, and bottom dissolved oxygen levels were slightly higher than surface readings in the western channel.

Water temperatures on November 14 were consistent throughout the channel within a half a degree, with surface temperatures ranging from 14.2 °C at Station 1 to 14.6 °C at Station 12. Bottom temperatures ranged from 14.2 °C at Station 10 to 14.4 °C at stations 1, 2, 6, 7 and 8 (Figure 7-3).

Flow rates past Vernalis continued to decline from 2,043 cfs on November 1 to 1,546 cfs by the 30th. Net daily flows past Stockton also fell markedly from 1,828 cfs on November 1 to 233 cfs by November 30 (Figure 7-4). The reduced flows seen at Stockton coincided with the removal of the Barrier, which allowed a diversion of flow from the San Joaquin River down Old River.

December

Dissolved oxygen readings remained steady in the west and central channels, but declined slightly in the eastern channel during December; however, all levels were well above state objectives. On December 10, surface dissolved oxygen levels ranged from 6.9 mg/L at stations 12 and 13 to 9.4 mg/L at stations 2 and 3. Bottom dissolved oxygen levels ranged from 6.9 mg/L at stations 12 and 13 to 9.3 mg/L at Station 1 (Figure 7-2). The western channel exhibited the highest dissolved oxygen, and all stations maintained surface dissolved oxygen levels above 6.9 mg/L.

Water temperatures throughout the channel declined further from November, and were consistent throughout the channel, within a half a degree Celsius. On December 10, surface temperatures ranged from 11.0 °C at stations 4, 5 and 6 to 11.5 °C at stations 10 and 11. Bottom temperatures ranged from 11.0 °C at stations 4, 5, 6, and 7 to 11.4 °C at Station 10 (Figure 7-3).

Flow rates past Vernalis in December ranged from 1,400 to 1,753 cfs, with an increase of flow occurring towards the end of the month. Net daily flows past Stockton continued to decline, with negative flows and flows approaching zero recorded on several occasions. December net daily flows at Stockton ranged from 573 to -150 cfs.

Stockton Turning Basin

Stratified dissolved oxygen conditions were recorded in the Stockton Turning Basin (Basin) (Station 14) throughout much of fall 2003 (Figure 7-2). Surface dissolved oxygen levels in late September and October were supersaturated, while bottom levels were at or below state objectives. The highest stratification was observed on October 8 when sampling showed surface dissolved oxygen concentrations of 16.0 mg/L, with a bottom concentration of 5.1 mg/L. Vertical dissolved oxygen stratification at Station 14 was observed on all sampling runs except the final run of December 10.

The periodic dissolved oxygen stratification appears to be the result of localized biological and water quality conditions occurring in the Basin. The

Basin is at the eastern dead-end terminus of the ship channel and is subject to reduced tidal activity, restricted water circulation, and increased residence times when compared to the remainder of the channel. As a result, water quality and biological conditions within the Basin have historically differed from those within the main downstream channel, and have led to extensive late summer and fall algal blooms and die-offs. The late summer and early fall of 2003 were no exception, as intense algal blooms composed primarily of green algae, flagellates, diatoms, and Cryptomonads were detected.

Stratified dissolved oxygen conditions often occur in the water column as a result of these blooms. At the surface, these blooms are highly productive and can produce markedly high surface dissolved oxygen levels. However, dead or dying bloom algae can sink to the bottom to contribute to high BOD and low bottom dissolved oxygen levels. Bottom dissolved oxygen levels in the basin are further degraded by additional BOD loadings in the area from sources such as regulated discharges into the San Joaquin River and nonpoint pollution adjacent to the basin. When bloom activity subsides, the dissolved oxygen stratification is reduced, and basin surface and bottom dissolved oxygen levels become less stratified.

Summary

Dissolved oxygen concentrations in the eastern Stockton Ship Channel fell below both the State's 5.0 mg/L and 6.0 mg/L objectives in August and September 2003, a period which coincided with relatively low net flows in the San Joaquin River past Stockton and warm water temperatures. A temporary barrier across the head of Old River was installed on September 15, 2003, to increase flows down the San Joaquin River into the channel. The Barrier became fully operational on September 22 when all culverts were closed. Subsequent sampling on October 8 showed an improvement of dissolved oxygen conditions, with all stations showing levels above the 5.0 mg/L objective and only the central channel with levels slightly below the 6.0 mg/L objective. By October 28, dissolved oxygen levels had improved to 6.0 mg/L or greater throughout the channel and remained above state objectives for the remainder of the sampling program. The Barrier was fully removed by November 13, and although flows past Stockton were subsequently reduced, dissolved oxygen levels remained within compliance. The fall sampling program was suspended after sampling on December 10.

References

[APHA] American Public Health Association. 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th Edition. Washington, D.C.

[CVRWQCB 1975] Central Valley Regional Water Quality Control Board. 1975. *Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board Central Valley Region, the Sacramento River Basin, and San Joaquin River Basin*. First Edition.

[CVRWQCB 1998] Central Valley Regional Water Quality Control Board. 1998. *Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board Central Valley Region, the Sacramento River Basin, and San Joaquin River Basin*. Fourth Edition.

[SWRCB] State Water Resources Control Board. 1995. *Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Estuary*. Adopted May 22, 1995, pursuant to Water Right Order 95-1. Sacramento, CA. 44pp.

Figure 7-1 Monitoring sites in the Stockton Ship Channel

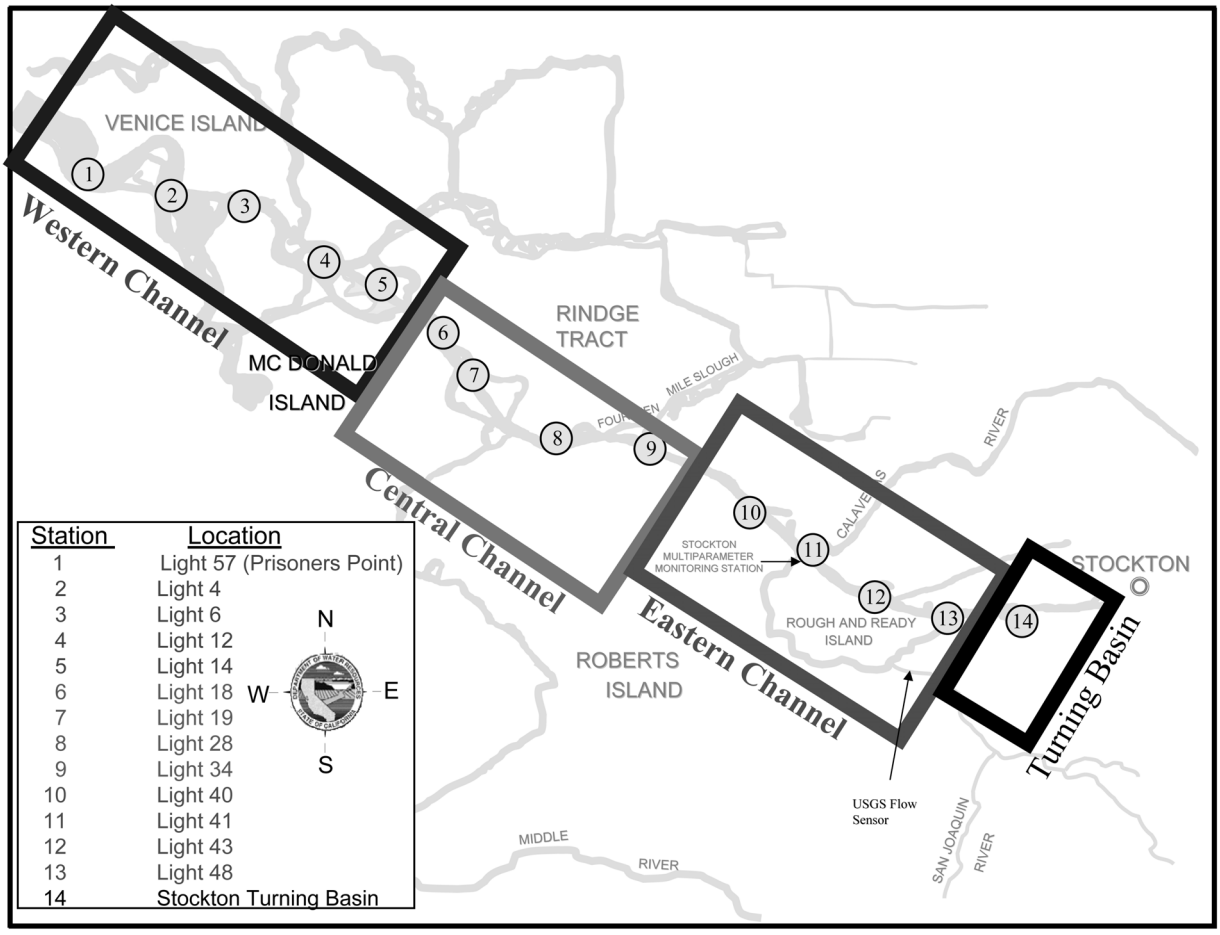

Figure 7-2 Surface and bottom dissolved oxygen concentrations in the Stockton Ship Channel, Fall 2003

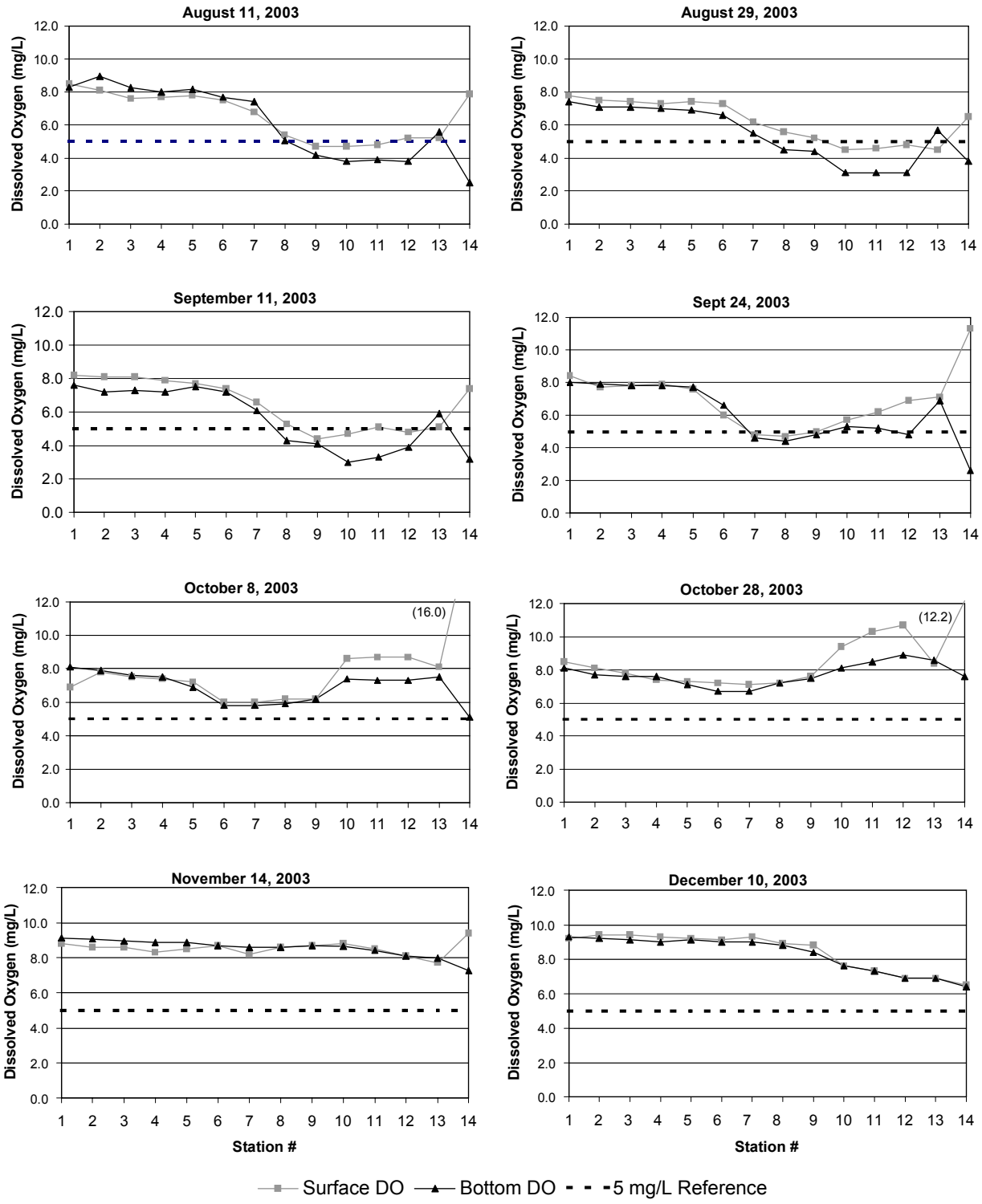

Figure 7-3 Surface and bottom water temperatures in the Stockton Ship Channel, Fall 2003

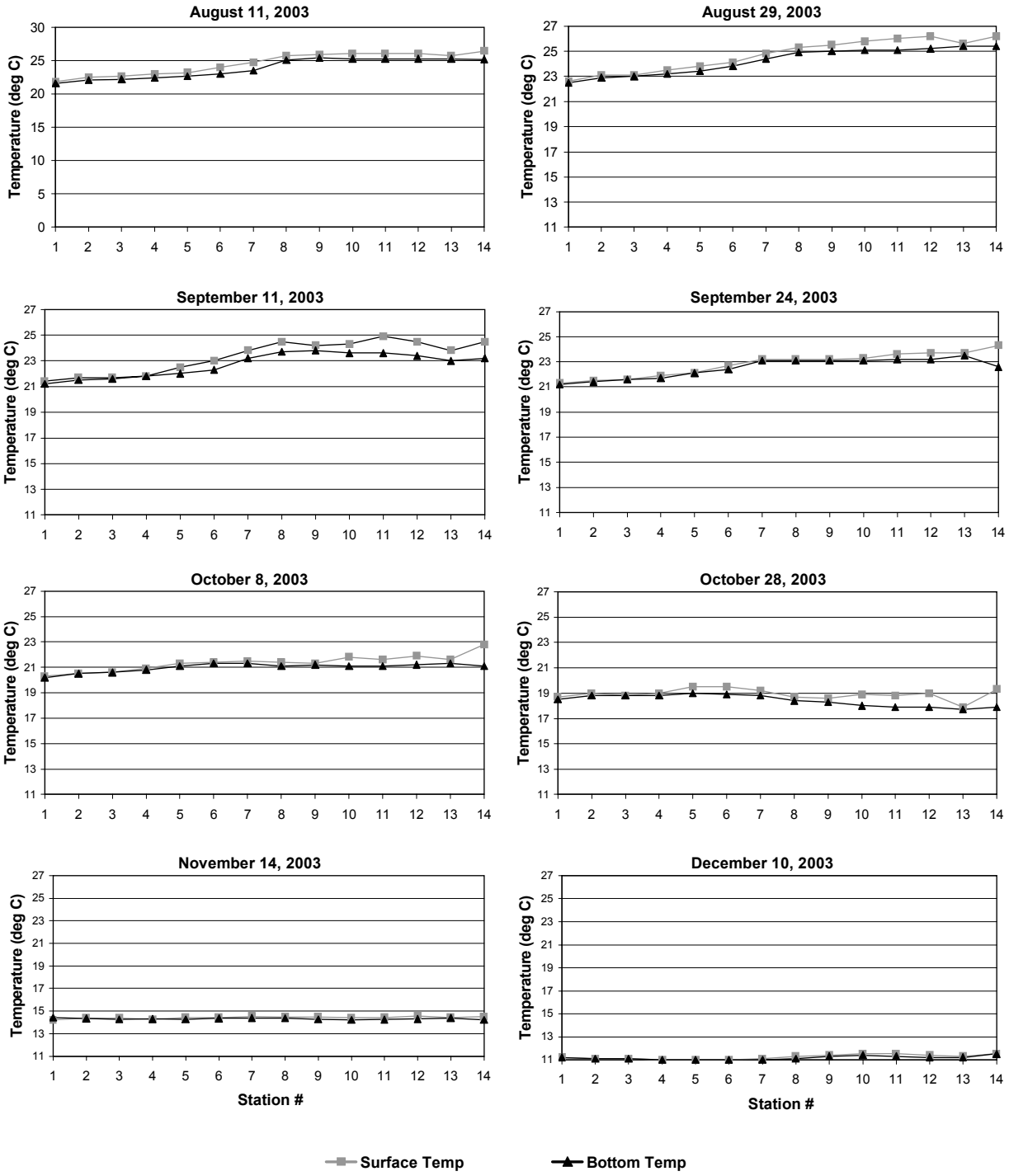

Figure 7-4 Fall 2003 San Joaquin River Flow at Stockton and Vernalis